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ISOKINETIC STRENGTH TRAINING IN BELOW-KNEE AMPUTEES

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ABSTRACT. Eight below-knee amputees performed isokinetic training of knee extensor- and knee-flexor muscles for a period of 8–12 weeks at angular velocities of 60°/s, 180°/s and 240°/s. Before and after training isokinetic and isometric knee extensor/flexor strength was measured. Muscle biopsies were taken from the vastus lateralis and the cross-sectional area of the thigh muscles was measured with computerized tomography. Peak torque of the amputated leg increased significantly in all knee-extension tests and in knee-flexion at 180°/s, and in the non-amputated leg in extension at 180°/s, 240°/s and for isometric strength at 60° knee angle. Knee-flexion strength increased at 240°/s. The cross-sectional area of the muscle fibers increased in the amputated leg in all patients except one. There was no significant increase in the non-amputated leg which also was trained. The quotient between the cross-sectional areas of type II and type I fibers increased from 1.04 to 1.20 in the amputated leg, demonstrating an increase specially in the type II fibers. There was no difference in the non-amputated leg. The cross-sectional area of the thigh muscles did not show any significant change in either leg. The patients estimated their ability to walk after training to more than double the distance compared to before training. They could also manage better without walking aids. The increase in strength and the synchronous increase in the size of type II (fast twitch) fibers indicate that the training model has activated also these motor units which probably have not been given as much training earlier.

Key words: isokinetic muscle training, below-knee amputees, prosthesis, muscle cross-sectional area, muscle morphology, muscle strength.

Below-knee amputated patients especially elderly have remaining muscle atrophy and weakness in the knee extensor and flexor muscles even after completed rehabilitation. Renström et al. (6) have shown that the amputees have a significant reduction with 35% of the cross-sectional area of the quadriceps muscle of the amputated leg compared to the non-amputated leg and that the mean muscle fibre area of the vastus lateralis of the amputated leg was reduced with 25% of that of the non-amputated leg. It was also shown that the amputees have pronounced weakness with more than 60% reduction in strenght compared to the non-amputated leg (5). Beside the muscle hypotrophy, inability to activate all motor units of the leg maximally and synchronously can contribute to the observed muscle weakness. This muscle weakness may furthermore be of clinical importance. Renström et al. (5) found that isometric and isokinetic knee-extension and flexion strength values in the amputated leg with prosthesis was significantly correlated to stride-length and maximal walking speed.

The aim of this study was to evaluate if below-knee amputees who had completed their rehabilition at the Amputee Training Centre could improve their strength further through specialized training and if and how this would influence their functional ability. For this purpose isokinetic muscle training was chosen as it has been demonstrated to be an effective training method (4).

MATERIAL

Eight male below-knee amputees were asked to participate. Their mean age was 61.5 (39–78) years. The time from the amputation to the start of the study was 2.5 (1.5–7) years. All the patients were retired from work. Four were amputated because of diabetes, two of arteriosclerosis, one of tumor and one of trauma. All the patients had a PTB prosthesis which they were wearing the whole day. The weight of the prosthesis varied between 1.5–2 kilograms. Nobody had limited range of motion in the joints of the lower extremities nor were they seriously troubled by phantom pain sensation or skin problems.

The number of participants was limited by the fact that the patients had to be motivated and able to follow the relatively demanding training program during the days. The selection of patients who could participate in this program excluded the possibility of a control group that was large enough.

Table I. *Average peak torque changes with training in the knee-muscles expressed in percent*

		Non-amputated leg		Amputated leg with prosthesis		Amputated leg without prosthesis	
		Ext.	Flex.	Ext.	Flex.	Ext.	Flex.
Isokinetic, angular velocity	60°/s	6	2	42*	12	17	13
	180°/s	11**	8	49*	22*	27*	18
	240°/s	10*	16*	36*	2	16	16
Isometric, knee angle	30°	26	18	68	4	43	23
	60°	27*	20	79**	7	32*	18

* $p<0.05$.
** $p<0.01$.

METHOD

A computerized Cybex II dynamometer (Lumex, New York) modified with a strain gauge (3) was used for the measurements of muscle strength. Knee-extension and flexion muscle strength was tested on the amputated and non-amputated legs with and without prosthesis. The patients were placed in a special chair and the pelvis as well as both thighs were fixed with straps. A light knee cushion was used and placed as distally as possible on the stump. A piece of thick rubber foam was used as a protection of sensitive stumps. The rotation axis of the dynamometer was aligned as close as possible to the transverse axis of the knee through the range of motion. The produced force was registered as torque (Nm). The measured values were corrected for the torque due to the weight of the measuring arm and the lower legs on both the amputated (stump and prosthesis) and non-amputated sides.

Isokinetic strength was measured as the torque during maximal voluntary knee extension and flexion at constant angular velocities of 60°/s, 180°/s and 240°/s. The produced force was measured from 90° of knee flexion (or the patient's maximal sitting knee-flexicon) to full extension. Three tests were performed. The patients rested for one minute between each test.

Isometric strength was measured at knee angles of 30° and 60°. Three tests were carried out with the patient resting for one minute between each test. The produced torque was registered on an oscilloscope (Tetronics) and photographed.

The patients were tested on two different occasions before training and on two different occasions after training. As the study aimed at evaluating the maximal strength of the patients the highest values were used.

The size of the areas below the torque angle curves was calculated manually with planimetry in order to use all the available information of the maximal torque curve through the range of motion. The curve for knee-extension was used between 30°–70° and for knee-flexion between 20°–60°. The reason for this was that the proper angular velocity should have been reached for the part of the curve which was used for the calculation.

Muscle biopsies were taken with a needle biopsy technique in both legs from the vastus lateralis at the depth of 2–3 cm (2). The location was chosen 20 cm proximal to the knee-joint. The biopsies were trimmed, mounted and frozen in cooled Isopentan (precooled with liquid nitrogen to −170°C). Histological evaluation for fiber classification and measurements of fiber areas were made as described earlier (1).

Computerized tomography using an EMI CT-1010 head scanner was made on both legs at the same level of the thigh as the biopsies were taken. The tomography was displaced on a screen and polaroid pictures were taken. Measurements were then done from an enlargement (4.1 times) of the picture. The areas of the whole quadriceps and the vastus lateralis muscles were measured with a planimeter.

Functional ability was assessed by using objective measurements including range of motion, circumference of the thigh, walking on plain surface and stairs on time. One patient was excluded from the latter two measurements because of blindness. The patients' estimated their walking distance and ability to walk on different kinds of grounds.

The training program consisted of five minutes of ergometer-cycling as warming up, followed by two sets of 10 repetitions of knee-extension and knee-flexion at each of the different speeds with a resting pause of two minutes between the two sets and five minutes between the change of speeds. Both legs were trained. The amputated leg was trained without prosthesis since training with the prosthesis could produce pain. The patients trained 2–3 times a week. The average number of sessions was 20 (18–42) times.

Wilcoxon's non-parametrical test was used for the statistical analysis and the level of significance is given in the text.

RESULTS

Peak torque increased significantly after training the extensor muscles of the amputated leg and more when they were tested with prosthesis than without after the training (Table I, Fig. 1). There was also an increase in the non-amputated leg. Results were calculated as percent increase in torque, due to the fact that the individual values varied.

There was a significant increase (17%) in peak

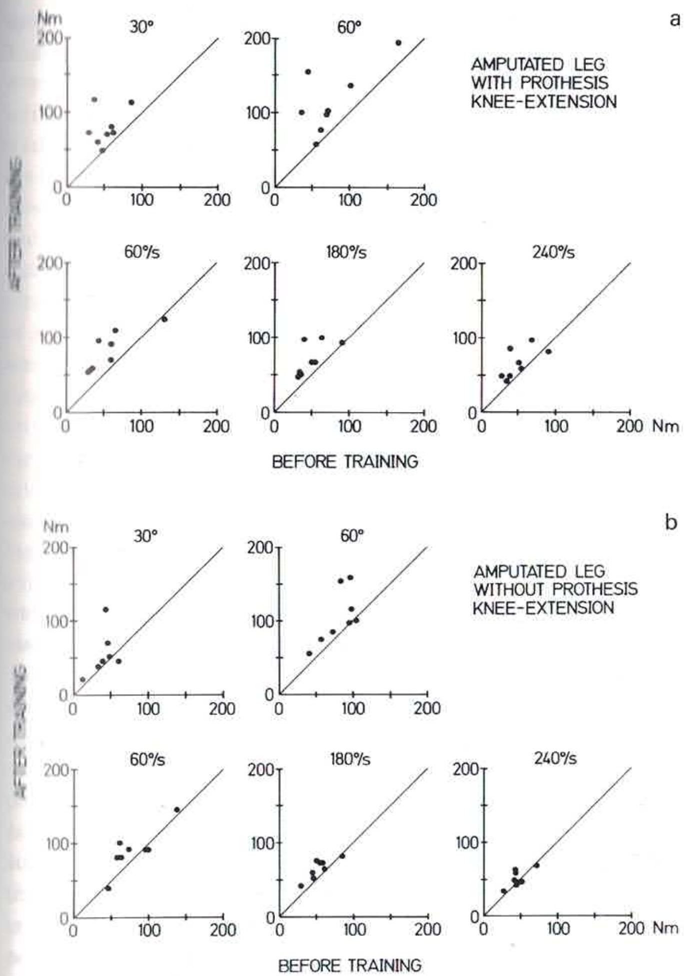

Fig. 1. Peak torque values in the knee extensor muscles in the amputated leg with prosthesis (*a*) and in the amputated leg without prosthesis (*b*) at isometric contractions (30°, 60° knee angle) and at isokinetic contraction (60°/s, 180°/s, 240°/s) before and after training.

torque in the non-amputated leg concerning knee-flexion at 240°/s ($p<0.02$), and in the amputated leg with prosthesis at 180°/s (22%, $p<0.02$). There was no increase in the amputated leg without prosthesis or in the isometric tests. The increases were overall larger for extension than for flexion.

The size of the area below the curves increased significantly in knee-extension in the amputated leg with prosthesis at 60°/s ($p<0.01$), 180°/s ($p<0.01$) and at 240°/s ($p<0.05$). The area increased significantly in the non-amputated leg at 240°/s ($p<0.05$). In knee-flexion the area increased only in the non-amputated leg at 240°/s (0.02).

The quotient between knee-extension and -flexion muscle strength increased significantly after training only in the amputated leg with prosthesis at 240°/s and in the isometric tests at 30° ($p<0.02$) and at 60° ($p<0.05$). The mean values of all the tests in the amputated leg with prosthesis increased with training from 1.2 to 1.6.

Muscle biopsies from the vastus lateralis did not show any significant change in the fibre composition after training (Table II). The mean cross-sectional area of the muscle fibres increased in the amputated leg in all patients but one and the increase was mainly in the fast twitch (type II) fibres. Thus, the ratio between the mean cross-sectional area for the fast twitch (type II) and slow twitch (type I) fibres increased with training from 1.04–1.20. In the non-amputated leg neither the mean cross-sectional area of the muscle fibres nor the quotient between the cross-sectional area for the type II and type I fibres showed any systematic increase.

Computerized tomography did not show any significant increase of the cross-sectional areas of the knee extensor muscles after training. The cross-sectional

Table II. *Fiber frequency, mean fiber areas and area ratios in the vastus lateris muscle before and after training (mean ± SEM) in six patients*

	Non-amputated leg		Amputated leg	
	Before training	After training	Before training	After training
Fiber frequency (%)				
Type I	51.3±7.3	49.0±6.2	38.7±8.6	56.2±6.4
Type IIA	30.7±5.8	30.0±6.0	15.3±3.2	15.7±3.2
Type IIB	17.0±3.5	20.0±0.8	41.5±10.1	22.3±5.6
Mean fiber area (μm × 10^3)	4.03±0.56	4.60±0.69	3.14±0.36	4.22±0.90
Area				
Type I	4.28±0.67	4.45±0.51	3.21±0.42	3.97±0.92
Type IIA	4.29±0.54	4.85±0.76	3.44±3.15	4.09±0.43
Type IIB	3.55±0.44	4.21±0.69	3.05±0.45	4.26±1.18
Area ratio				
Type II/I	0.97±0.09	1.01±0.07	1.04±0.11	1.20±0.04

area of the quadriceps muscles of the amputated leg was 47.5 ± 12.1 cm² before training and 48.8 ± 13.8 after and in the non-amputated leg 63.1 ± 12.0 cm² before and 64.8 ± 13.0 after. The relation between the amputated leg/the non-amputated leg was before training 72.3% and after training 75.3%.

Functional ability improved after training as all the patients estimated their walking ability to be more than double the distance after training compared to before. With walking aids their estimated mean walking ability increased significantly ($p<0.01$) from 3.2 (0.25–10.0) km to 6.6 (0.7–20.0) km and without walking aids from 1.3 (0.02–4.5) km to 3.0 (0.05–10.0) km ($p<0.01$). Two patients had after the training remaining walking problems when walking up and down hill and on irregular surface. The patients were able to manage better without walking aids after training but liked to keep them for safety reasons. No significant changes were recorded in the speed of walking neither on plain surface nor in stairs. The mean time for walking 30 m with maximal speed was 22.15 (20.5–23.5) before training, and 21.3 s (17.5–22.3) after training. The corresponding figures for spontaneous speed were 27.15 (23.5–30.0) and 27.8 s (24.7–31.0) respectively. The mean time for stair-walking one floor with maximal speed was 37.3 s (29–52) before training and after training 36.0 s (29–49). The corresponding figures for spontaneous speed were 51.1 s (38–104) and 52 s (38–100) respectively.

The circumference of the thigh (measured 15 cm above the knee joint) did not show any significant change after training in either leg. The mean value before training was 42.7 (36–50) cm in the non-amputated leg and 40.4 (37–47) cm in the amputated leg and after training 42.7 (38–47.5) cm and 40.0 (33.5–44.5) cm.

DISCUSSION

The strength of the amputated leg with and without prosthesis was considerably reduced in below-knee amputees when compared to the non-amputated leg, as shown previously (5), and also when compared to healthy 70-year-old men (1). In spite of the fact that many below-knee amputees manage their ADL activities and live a fairly active life, their muscle strength is still considerably reduced. It was therefore considered to be of value to study if a specialized training period could increase the strength. This was especially interesting as the thigh muscle strength is correlated to walking capacity (5).

The present study has shown that the strength of the knee-extensor muscles of the amputated leg with prosthesis increased in the order of 40–79% in the different tests compared to an increase in the order of 16–43% for the amputated leg without prosthesis. The strength of the non-amputated leg increased in the order of 6–27%, i.e. the increase was not of the same magnitude as in the amputated leg. Using the area under the torque-angle curve did not increase the amount of information but gave less number of significant differences. The strength of the amputated leg with prosthesis was 50% of the strength of the non-amputated leg before training and 60% after. The strength of the non-amputated leg after training was similar to the strength in 70-year-old men described by Aniansson et al. (1). Results of the present study indicate therefore that it is possible to increase the strength of the knee muscles, especially the extensors, with specialized training in both the amputated and non-amputated legs. At the same time the cross-sectional area of the fast twitch (type II) fibres increased with training in the amputated leg but this is of a smaller magnitude than the strength increase. It seems that the training model thus activated also those motor units which earlier probably did not receive as much training and the discrepancy between the effect of training on strength and of fibre area might at least partly be explained by a more ample and synchronous activation of motor units after training. However, the atrophic muscles in below-knee amputees can also be changed morphologically with training. Evidently the training effects on strength were larger on extensor than on flexor muscles.

The improvement in strength was greater in the amputated leg when it was tested with prosthesis than without. One reason for this could be that the pressure against the stump is higher when tested without the prosthesis and that the afferent impulses from this can cause an inhibition of the produced force. On the other hand when testing with prosthesis, the distal tibia can move towards the prosthesis which also might cause discomfort or pain and thus impair the produced force.

The state of the skin is of vital importance for test results and training possibilities. An occasional blister can reduce the ability to produce force because of pain—usually during a specific part of the range of motion. A badly fitting prosthesis can influence the result in a negative direction. Two patients had received a new prosthesis between the test occasions which may have influenced the results negatively.

The alignment of the rotational axis of the dynamometer to the transverse axis of the knee was controlled so that it should be as accurate as possible through the range of motion, but the alignment was difficult especially in the amputated leg. The zero position of the apparatus was 90 degrees. This angle was not always possible to achive in the sitting position, neither with prosthesis nor without, due to factors like the shape of the prosthesis, the size of the soft tissues and the length of the stump. The reproducibility of the starting position is thus uncertain which might affect the area values but not the peak torque.

Even if the patients trained without prosthesis they were able to use their increased strength to an even greater extent when wearing the prosthesis. This is further supported by the fact the patients estimated that their functional walking range had increased to more than double the distance. Renström et al. (5) have shown that knee-extension and flexion strength in the amputated leg with prosthesis is significantly correlated to stride length and maximal walking speed, the result at the walking test, however, not being changed after training in the present study. The patients may improve their self-confidence regarding their physical ability by improving their strength, as illustrated by the increase in estimated walking distance. The results from the present study indicate that below-knee amputees will benefit from specialized strength training in the rehabilitation process.

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